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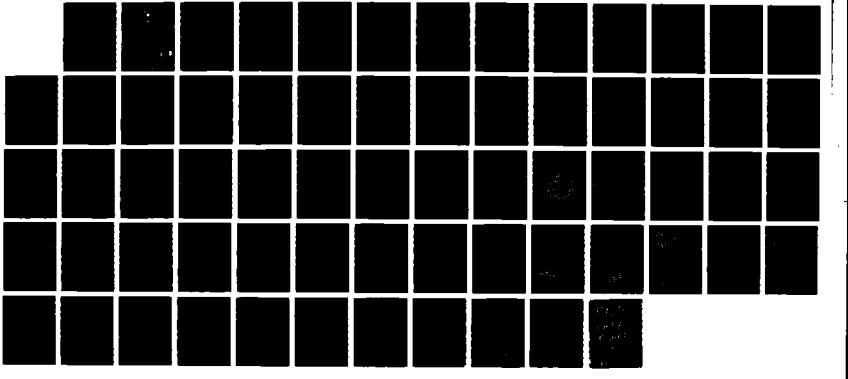

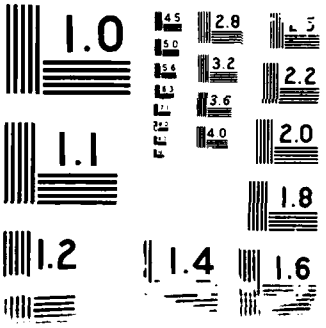
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DEVELOPMENT OF TECHNIQUES TO RELATE RADON LEVELS IN HOMES IN THE DAYTON AREA TO LOCAL GEOLOGY AND FILL MATERIAL

THESIS

Joseph P. Bouchard
Captain, USAF

AFIT/GNE/ENP/88M-2

DEPARTMENT OF THE AIR FORCE
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Wright-Patterson Air Force Base, Ohio

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THESIS

Presented to the Faculty of the School of Engineering

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the

Requirements for the Degree of

Master of Science in Nuclear Engineering

Joseph P. Bouchard, B.S.

Captain, USAF

March 1988

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Preface

The purpose of this study was to develop techniques which could be used by future AFIT students to relate radon levels found in homes in the Dayton area to fill material or local geology. The effort consisted of several related efforts including measuring radon levels in Dayton-area homes, making a Lucas cell for measuring radon emanation from fill material, and developing a radon chamber.

The radon measurements made of Dayton-area homes were divided into zip code regions and the resulting pattern indicated a larger percentage of elevated radon levels toward the north and east of Dayton.

The Lucas cell for measuring radon emanation from fill material was built and used to measure radon emanation from a fill material sample.

The radon chamber consisted of a glovebox connected to a continuous Lucas cell monitor. An exposed 0.1 μCi radium source in HCl solution was examined initially as a radon source which created a corrosive environment. The source was then covered by several materials and eventually allowed to evaporate to examine the effect on the chamber radon concentration.

I would like to thank my advisor, Dr John, for his assistance with all my thesis work and Bob Hendricks for his help in the laboratory. I would also like to extend my appreciation to the AFIT Shop for their help.

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ABSTRACT

Techniques were developed which will allow indoor radon measurements taken in the greater Dayton area with charcoal canisters to be related to local geology or fill material. A Lucas cell was built and calibrated for measuring radon emanation from fill material and a procedure was developed to find the radium content of fill material. Studies to attempt to determine the best radon source for a radon chamber were also made. Radon diffusion properties of three polyethylene-type materials were studied for possible use as moisture barriers in the charcoal canisters or as radon source covers.

The radon measurements taken showed a higher percentage of elevated radon measurements above 6.0 pCi/l in homes to the north and east of Dayton. This was based on 107 first floor measurements and 76 basement measurements.

Radon chamber studies were conducted on several radon sources including radium in HCl solution and evaporated sources. A clear advantage is demonstrated for the evaporated radon source. The ability of the glovebox to maintain a build-up of radon was also shown.

Radon emanation from fill material was measured using a Lucas cell modified to hold fill material in the cell. The ability of the Lucas cell to determine radon emanation is clearly demonstrated with an equilibrium time of just over two weeks.

A procedure for determining the radium content of fill material was developed using a NaI detector. Before the procedure can be used, however, an efficiency for the fill material in the geometry used must be measured since it was not done in this study.

Radon diffusion properties of condom material, Glad wrap, and Silastic material show that Glad wrap and condom material are nearly nonpermeable to radon, while Silastic has a 200-hour halflife for radon diffusion from inside the canisters. This indicates that Glad Wrap and condom material would not be useful as moisture barriers or source covers.

I. Introduction

Purpose

The purpose of this thesis was to develop the techniques necessary to conduct a study of radon in homes in the greater Dayton area and relate those radon levels to local geology or fill material. To support this effort, work was done on the development of a radon chamber which will be used for calibration and other radon studies.

Background

Radon-222 is a naturally occurring noble gas nuclide which is formed from the decay of radium-226 (halflife 1600y). Since radon is a noble gas nuclide with a halflife of 3.82 days, it readily diffuses through soils into mines and buildings where it can build up in significant concentrations. The decay of radon-222 by alpha emission is followed by a rapid succession of decays to various reactive progeny as shown in Figure 1 and Table I. Since the progeny are often positively charged, they readily attach to dust or other surfaces they contact. If this

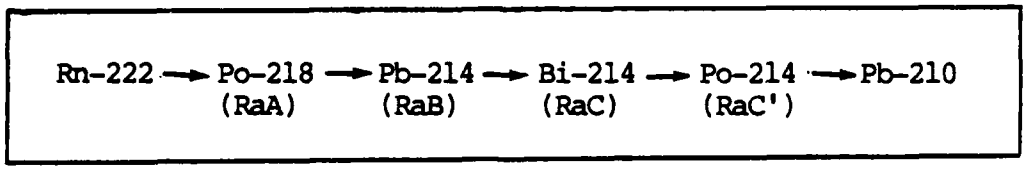

Figure 1. Radon Decay Scheme

TABLE I: RADON-222 AND IMPORTANT PROGENY DECAY DATA

NUCLIDE	HALFLIFE	DECAY MODE	IMPORTANT ENERGIES (MeV)
Rn-222	3.82 days	alpha gamma	5.49 0.512
Po-218	3.05 min	alpha	6.00
Pb-214	26.8 min	beta gamma	0.67, 0.73 0.35, 0.30
Bi-214	19.8 min	beta gamma	Several energies 0.242, 0.295, 0.352
Po-214	163.7 μsec	alpha	7.69

surface is the respiratory tract of man, the energy of the decays will deposit in tissue and increase the risk of lung cancer. The Environmental Protection Agency (EPA) considers chronic exposure to a level of 0.02 Working Level (WL) or higher to be an unacceptable risk and recommends mitigation in the near future (6:8). A level of 0.02 WL corresponds to a radon level of 4.0 pCi/l if the actual concentration of radon progeny is half that of the equilibrium level. A complete explanation of WL is presented in Appendix A.

The threat from radon has led to many studies on the cause and source of elevated radon levels in homes. Geology, fill material, and

building materials have been studied as radon sources. Radon is known to emanate from each of these sources in varying levels depending on their radium content. Understanding how these sources combine to create elevated radon levels in some homes, while not in others, is important if radon mitigation is to be successful.

Measuring Radon. Detection of radon and its progeny is a difficult process. Many methods have been developed including alpha track detectors for integrated measurements over long periods of time and charcoal canisters for integrated measurements over several days (5:992). Lucas scintillation cells are used for instantaneous or "grab sample" radon measurements and the modified Tsivoglou method is used for determining the concentration of radon progeny in air (7:783-787).

Scope of Thesis

In this study the techniques were developed which will allow radon measurements made from Dayton-area homes to be related to local geology or fill material. Charcoal canisters, developed by Cohen (1:501-508) and built by Gill (4:45), were used to collect radon samples in homes and the results were divided by zip code regions to examine possible patterns. A Lucas cell was built and calibrated for measuring radon emanation out of fill material and a procedure was developed using a NaI detector for determining the radium content in fill material. A radon chamber was built as a source of radon in the laboratory and various factors were studied to enable a final design of a radon chamber

to be made. The factors examined included the radon source, the radon stability within the chamber, and radon leakage from the chamber. Charcoal canisters were used to measure radon diffusion properties through three polyethylene-type materials which could be used as radon chamber source covers or as moisture barriers on charcoal canisters.

II. Experimental Design

Radon Chamber

A radon chamber was built to achieve a constant radon source for radon measurements. The radon chamber was a closed system consisting of a 250 liter glovebox and a continuous radon monitor connected with Evenflow tubing as shown in Figure 2.

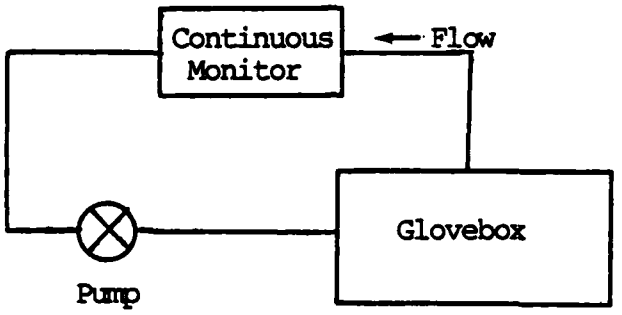

Figure 2. Radon Chamber Schematic

Outside access to the glovebox was through a double-sealed side port. A clamped tube on the top of the glovebox was used for grab sampling.

Radon source. An 850 ml beaker containing 0.1 μCi of Radium-226 in HCl solution was the radon source through most of the study. The beaker was covered with a 5 mil sheet of polyethylene for one month, then a 5 mil sheet of Silastic sheet for two months. Near the end of the study the source was removed and HCl solution allowed to evaporate. A 100 μCi radium source was placed in the glovebox. After one week, the 100 μCi source was removed and the evaporated 0.1 μCi source placed back into the

glovebox. The layout of the glovebox is shown in Figure 3.

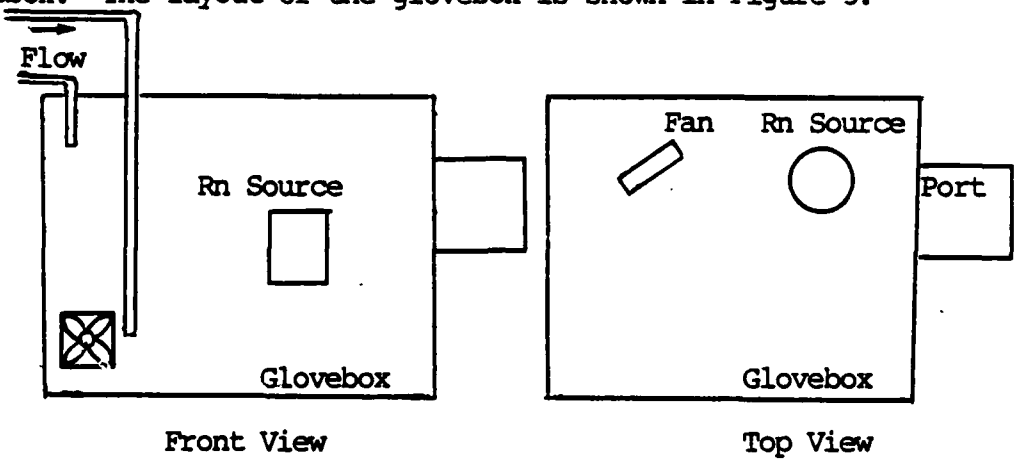

Figure 3. Radon Chamber Layout

Temperature and humidity inside the chamber were monitored on a weekly basis with a humidistat. A Nuclear Data (ND) 680 multichannel analyzer was used in the multiscale mode to monitor the counts from a continuously operated Lucas cell. A counting interval of 400 seconds was used throughout the study period.

Lucas Cell Detection System. The Lucas cell detection system was set up as shown in Figure 4.

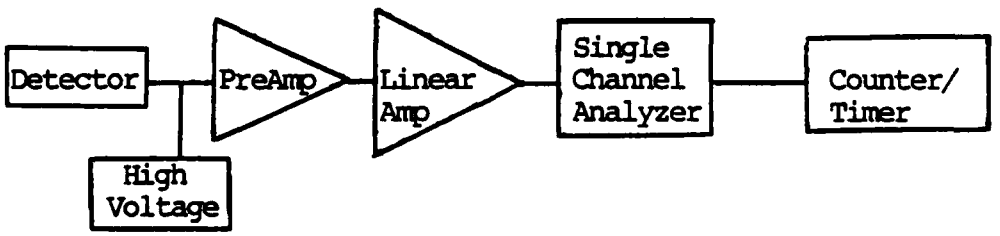

Figure 4. Lucas Cell and Continuous Monitor Detection System

The detector consisted of a Lucas cell which set on top of a photomultiplier tube. A detailed description is found in Appendix B. "Grab samples" from Mound Laboratory, Miamisburg Ohio, of known radon concentration were used to calibrate the Lucas cell. Helium flushing was used between grab samples to eliminate any remaining radon.

Continuous Radon Monitor

The continuous radon monitor was a Lucas cell with tubing to allow air to flow through the cell. The detector was connected as shown in Figure 4 and a complete description of the detector is given in Appendix B. It was connected to the radon chamber to monitor the radon level within the chamber during various studies.

Fill Material

A procedure to determine the radium content of fill material and a method to determine the radon emanation from fill material were developed. The procedure to determine the radium content of fill material uses a NaI detector while radon emanation from the fill material is measured using a modified Lucas cell.

Lucas Cell. The modified Lucas cell for measuring radon emanation is described in Appendix B. It contains a wire basket in the top of the cell to hold the washed fill material. Once the fill material was placed in the cell it was sealed and placed over a photomultiplier tube. Counts from the cell were monitored sequentially for 1000 second intervals to

required for the cell to come to equilibrium. The Lucas cell was calibrated using a grab sample from the radon chamber which was at known concentration.

Theory (3:264). The differential equation for radon emanating through a porous medium is given by

$$\frac{k}{p}\frac{dC}{dx} - \lambda C + \frac{P}{p} = 0 \qquad (1)$$

where
p - Porosity of medium [Interstitial vol/Total vol]
P - Gas emitted by solid matrix of medium [Atoms/sec-cm^3]
k - Effective diffusion constant
C - Concentration of diffusing gas [Atoms/cm^3]
λ - Decay constant [sec^{-1}]

At equilibrium, Equation (1) becomes

$$P = \lambda C p \qquad (2)$$

This allows the gas emission from the solid matrix to be calculated.

Radium Content. The procedure to determine the radium content of fill material uses a 3 inch X 3 inch NaI scintillator for monitoring counts from a sealed container filled with fill material. The fill material was cleaned and dried prior to being sealed in a plastic container. Four-hour measurements were taken weekly over a four week period to determine if any build up of radon might occur within the

container. From this information and the detector efficiency, the radium content can be calculated.

Radon in Homes

Charcoal Canister Calibration. Radon measurements were taken in the greater Dayton area using charcoal canisters. These canisters had been calibrated for seven-day integrated counts by Gill (4:45) based on the work of Cohen (1:501-508). The canisters were recalibrated to three-day integrated counts for this study to attempt to reduce humidity effects and accelerate the rate of data collection. The recalibration was accomplished by taking 10 of the 45 total canisters to Mound Laboratory and exposing groups of the canisters in the climate controlled radon chamber. Four of the canisters were exposed for three days at 50% humidity, three of the canisters were exposed for three days at 80% humidity and three of the canisters were exposed for three days at 25% humidity. The canisters were measured on a NaI detector for 30 minutes with gamma counts made between 220-390 keV and 550-680 keV.

The results of the gross gamma counts in the energy regions of interest were used as input to the program "RADON" which was written by Weidner (8:47) and is listed in Appendix C. Also information on the time since the canisters were sealed and background gamma counts in the regions of interest were used as input. The program then calculates the net gamma counts, corrects for radioactive decay, and computes the radon concentration in pCi/l. Based on the results obtained from the

canisters, no modification of the program was necessary for the change to three-day exposures since the measurements obtained were within 8% of actual radon levels in all cases. The results of the measurements are given in Table II.

TABLE II: Charcoal Canister Calibration

Humidity Exposure	Average Radon Conc. Measured in (pCi/l)	Mound Chamber Radon Level (pCi/l)
50 %	47.04	49
80 %	48.58	50
25 %	59.35	55

Measurement Method. The canisters are ointment cans, 1 inch by 3 inches in diameter, partially filled with activated charcoal. A complete description of the canisters can be found in Appendix B. The canisters were left exposed to the air for three days. Gamma count times for the canisters were 30 minutes and the energy regions counted were between 220-390 keV and 550-680 keV. The canisters were counted on a NaI detector using a ND 680 multichannel analyzer. One canister was given to homeowners with no basement while two canisters were given to those with a basement. One of the canisters was to be placed in the basement and one in a first floor room. A sample of the instruction sheet given with the charcoal canisters is shown in Appendix E. The gamma counts obtained from the energy regions were used as input to a computer program called "RADON". The output from the program was the radon concentration

in pCi/l. As the radon measurements were collected, they were coded and placed on a Dayton-area map. The code used is shown in Table III.

Table III: Radon Measurement Coding

Radon Level Found (pCi/l)	Color Code Used on Map
0.0 to 4.99	Blue
5.0 to 9.99	Yellow
10.0 to 14.99	Orange
15.0 to 19.99	Pink
20.0 to 29.99	Red
30.0 and Higher	Large Red

Measurements taken by previous AFIT students are included in the study. The measurements are listed by zip codes to make regional comparisons.

Radon Diffusion

Diffusion of radon through several polyethylene-type materials was examined. The materials were examined as a possible source cover for the radon chamber or covers for the charcoal canisters to keep moisture out. Special lids were made for the canisters with the material placed across the hole in the lid. Radon diffusion properties were examined by exposing several charcoal canisters in the radon chamber. The new lids were placed on the canisters and the radon within the canisters was allowed to diffuse through the material. By making gamma counts on the

NaI detector, and correcting for radon decay, the amount of radon diffusing from the canisters was found. These measurements were made daily until the counts within each energy region approached background levels. The canisters were sealed for two hours before being measured to allow the radon and progeny to approach equilibrium.

III. RESULTS

Radon Chamber

Several important facts were learned from radon chamber experiments. The main effort was concentrated on determining a source for radon in the chamber. Three sources were used including a 0.1 μCi source in HCl solution, a 0.1 μCi evaporated source, and a 100 μCi source in HCl solution.

0.1 μCi Source in HCl solution. This radon source gave mixed results. A continuous source of radon was obtained in the chamber using both the the 5 mil polyethylene and 5 mil Silastic covers over the beaker. The radon concentration varied between 25-35 pCi/l during most of the study, but was unstable at times, with extreme variations from a low of 20 pCi/l to a high of 45 pCi/l. When the cover over the beaker was loosened, the variations became less severe, but still occurred. Another problem which occurred with the silastic cover was that HCl fumes could be detected in the chamber. This indicated that silastic is permeable to HCl making the environment in the chamber corrosive. After two months the acid began to produce holes in the silastic from the inside of the beaker where condensation occurred.

0.1 μCi Evaporated Source. When the 0.1 μCi evaporated source was placed in the chamber, radon built up in the chamber and the problem of HCl fumes was eliminated. The radon concentration in the chamber as determined from the continuous monitor was between 30-40 pCi/l which

was slightly higher than with the source in HCl solution. The chamber was observed for 2 weeks and some variations in the continuous monitor counts observed. The variations observed were near those with the source in solution.

100 μCi source in HCl solution. The 100 μCi radium source gave a rapid build-up of radon in the chamber. A canister exposed for less than one day measured a radon level greater than 7000 pCi/l. Several canisters were exposed in the chamber for different lengths of time to observe the rate of radon diffusion into the canisters. The results are found in Table IV.

Table IV: Radon Diffusion into Canisters

Exposure Time in Chamber (min)	Concentration (pCi/l)
0.5	26.58 +/- 0.3
1.0	43.08 +/- 0.37
2.0	82.50 +/- 0.53
4.2	118.99 +/- 0.66
6.1	273.17 +/- 1.20
10.2	390.19 +/- 1.60
20.1	416.92 +/- 1.69

Due to concern over possible leakage from the chamber and short-lived alpha contamination of canisters, the source was removed from the chamber after several days.

Radon chamber leakage. Radon leakage from the chamber was expected since variations in the radon level were many times tied to changes in atmospheric pressure. A typical variation of radon in the chamber is shown in Figure 5. The leakage from the chamber was found by allowing the radon to remain in the sealed chamber after the source was removed. The only method of radon removal was by decay, absorption in materials, or leakage from the chamber. The rate at which the radon was removed from the chamber is shown in Figure 6. By correcting for decay, the leakage rate from the chamber was calculated. The effective halflife for radon in the chamber was found to be 10.5 hours compared with a radon radioactive halflife of 91.7 hours.

Fill Material

Lucas cell. Only one sample of fill material was examined using the modified Lucas cell due to the long equilibrium time. The fill material took over two weeks to come to equilibrium with the equilibrium level obtained near 5200 net counts/5000 seconds as shown in Figure 7. With the calibration factor of 0.151 +/- 0.007 cps/(pCi/l) the equilibrium radon level was 6.89 +/- 0.30 pCi/l. Using Equation (2), this corresponds to 8.63×10^{-5} atoms/(sec-cm^3) of radon gas emitted by the solid matrix of the fill material.

The results in Figure 7 show several discontinuities in the counts. The radon appears to come to equilibrium on at least two occasions. After counts were temporarily discontinued there is a jump in net

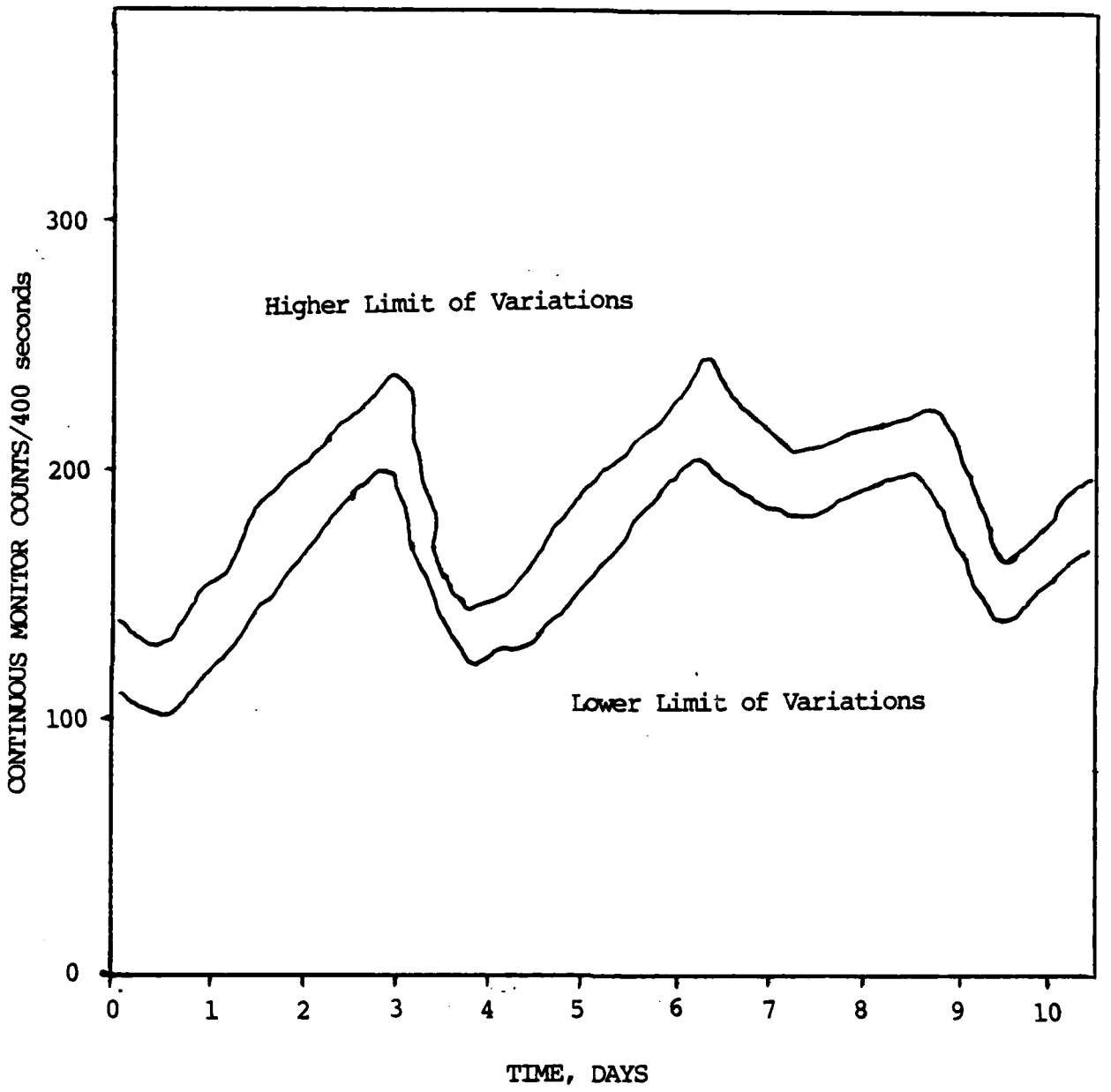

Figure 5. Typical Radon Chamber Radon Variations

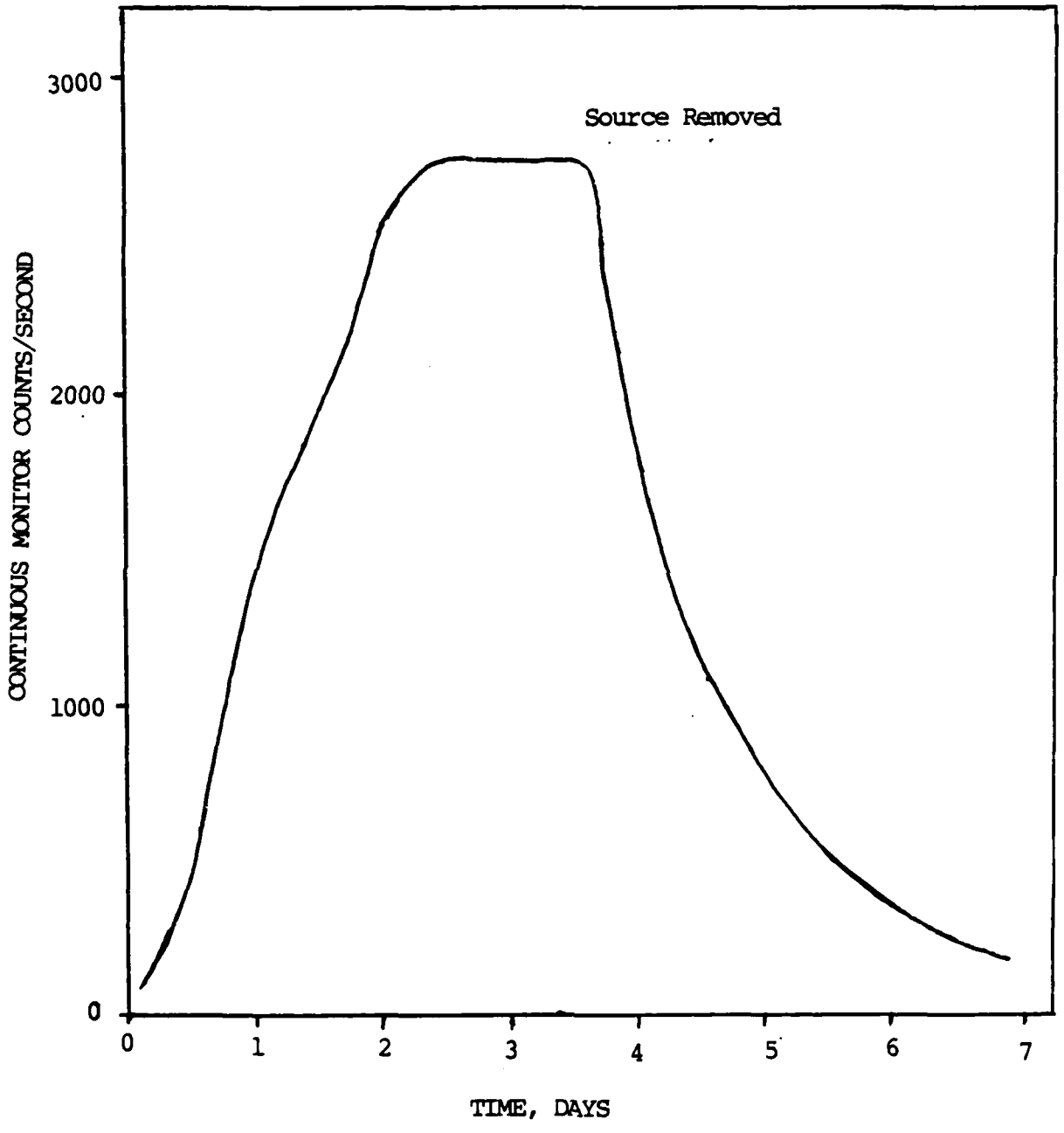

Figure 6. Radon Decay and Leakage From Chamber

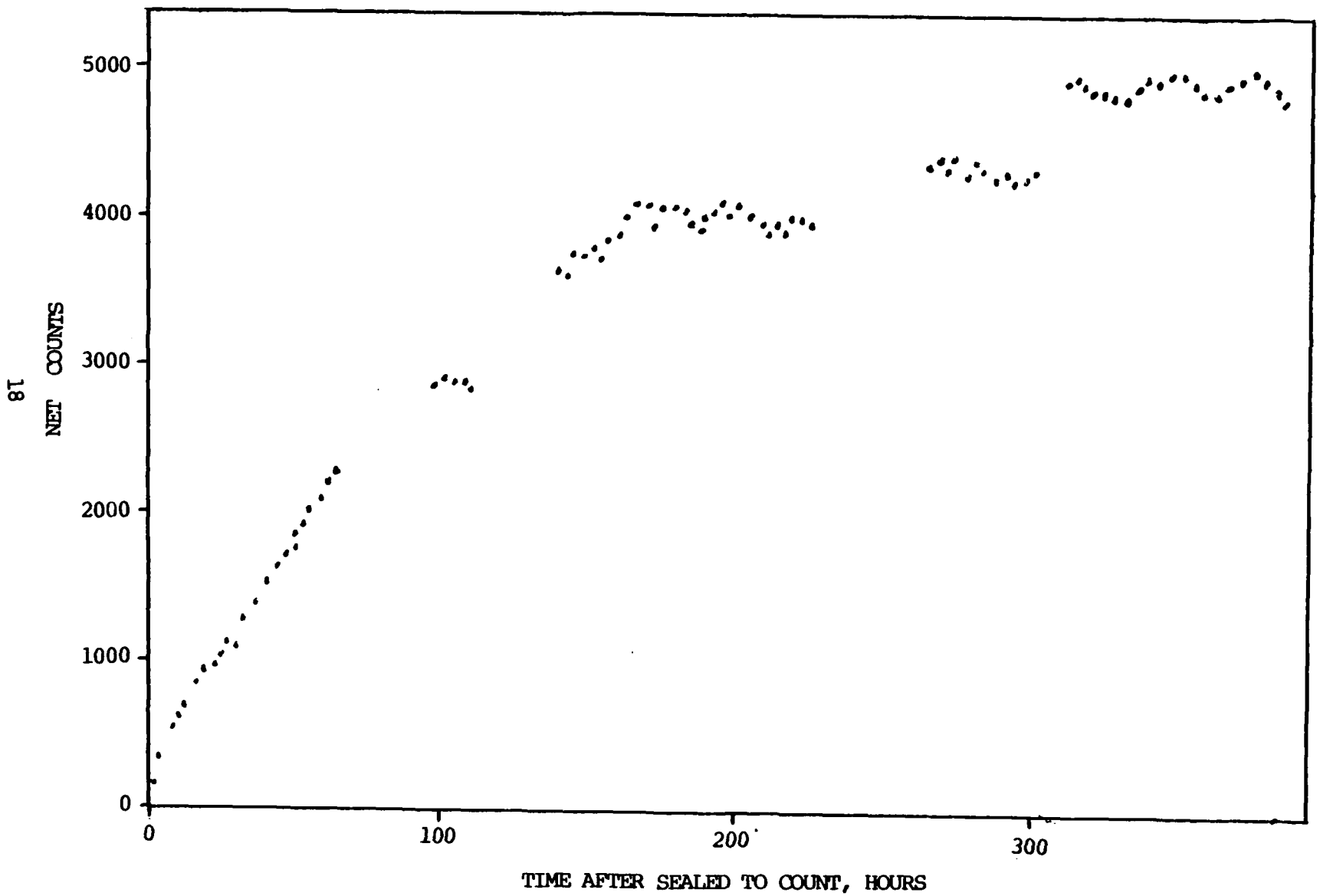

Figure 7. Fill Material Radon Emanation

counts. An explanation for this could be variations in the electronics used even though the same electronics were used at the same settings.

Radium Content. Five four-hour runs were made on the NaI detector of a fill material sample with a typical output shown in Figure 8. The runs covered a period of one month, with no detectable buildup of radon or progeny. This allowed the assumption to be made that the gamma counts detected initially in the fill material would not change. Due to the large background of gammas and the relatively small radon and progeny gamma counts, many measurements are required to get statistically significant counts. The typical total gross counts between 220-390 keV were 36000 counts, while net counts from radon and progeny were about 4500 counts. The variation from counting statistics alone is near 260 counts. A consistent method of determining the background spectrum is necessary for this method to give consistent results.

The efficiency of the detector for the geometry of the fill material is necessary before the actual radium content can be found. An estimate for the efficiency can be found by measuring a container filled with pure water and making a count for background. Then adding a known amount of radium to the solution another count could be made. Since the total amount of radium within the solution would be known, the ability of the detector in that geometry to detect the radium could be found. Making the assumption that the radium in the solution is similar to radium in fill material the efficiency could be used.

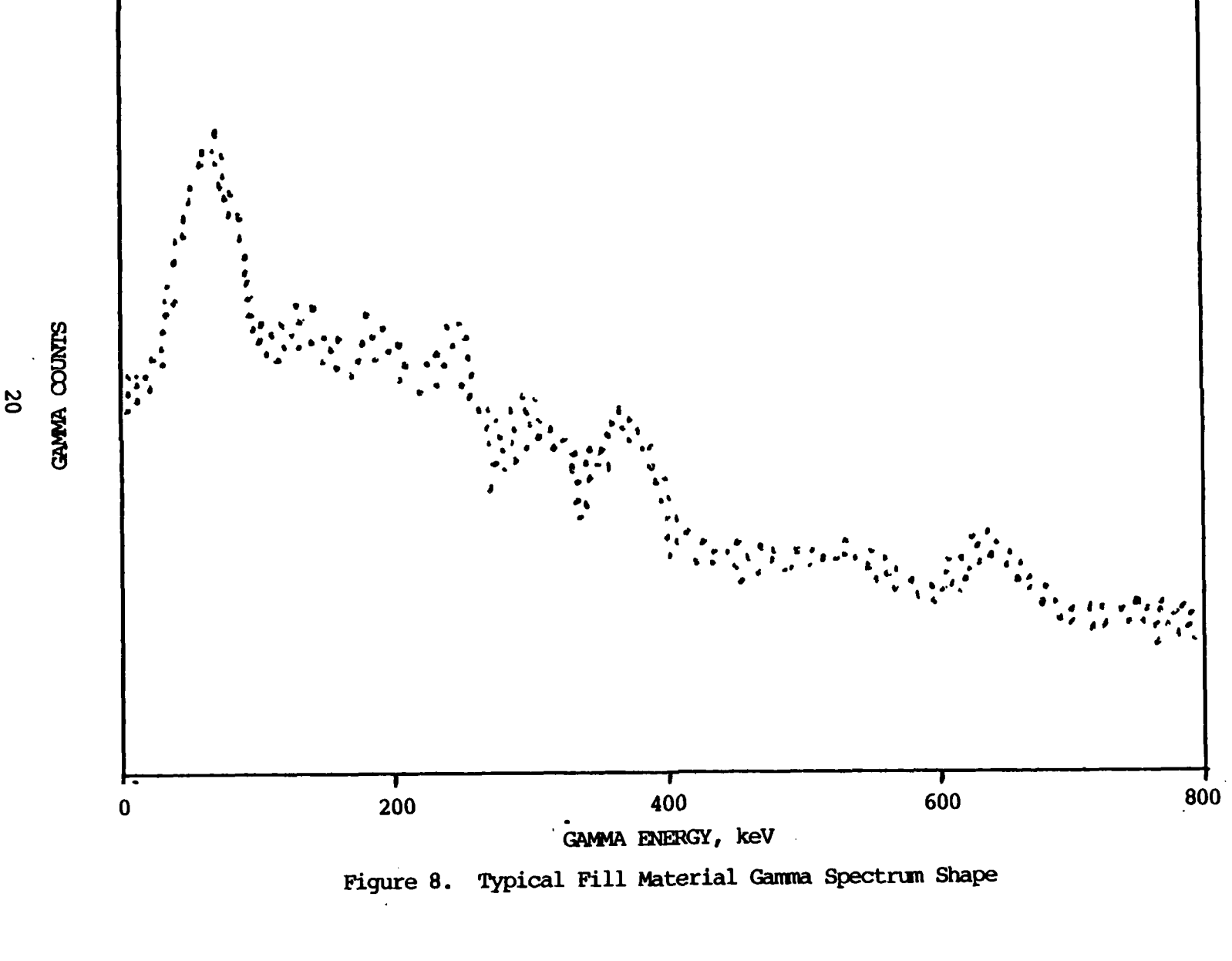

Figure 8. Typical Fill Material Gamma Spectrum Shape

Radon in Homes

The results of the radon measurements in homes are divided by zip code regions. The individual measurements are in Appendix D. Tables VI and VII show the results obtained by zip code region. 107 radon measurements were taken in first floor or main level room while 76 measurements were taken in basement or lower level rooms. The average value of the first floor measurements is 6.22 +/- 0.32 pCi/l with a median value of 3.70 pCi/l while the average of the basement locations is 10.75 +/- 0.36 pCi/l with a median value of 7.32 pCi/l. The distribution of the measurements is shown in Figure 9 for first floor measurements and in Figure 10 for basement measurements. A map showing the location of the zip code areas in relation to cities and towns is shown in Figure 11. The results of both measurement locations were plotted on log-probability paper and are shown in Figure 12 and Figure 13. The results are linear which indicates a log-normal distribution of the measurements. Key parameters of the distribution are summarized in Table IV.

Table IV: Radon Measurement Distribution Parameters in pCi/l

Location	Average	Mean	Deviation	Median	Alpha	Beta
First Floor	6.22+/-0.32	3.90	+/-1.06	3.70	1.36	3.00
Basement	10.75+/-0.36	6.75	+/-1.83	7.32	1.91	3.74

Table VI: Results of Radon Measurements in pCi/l (First Floor)

Zip Codes (Region)	Number of Measurements	Average	High	Low	Median
45432, 45459 & 45305 (Miamisburg/Bellbrook)	15	4.84	15.99	0.62	3.88
45440 & 45429 (Kettering)	12	4.30	13.90	0.30	2.99
45430, 45420, 45419 & 45409 (Beavercreek/Oakwood)	8	4.76	9.89	0.71	4.27
45432 & 45431 (Beavercreek/Riverside)	15	5.78	39.09	0.34	3.58
45385 & 45301 (Xenia)	9	7.82	18.60	0.78	8.47
45324, 45435, 45323 & 45387 (Fairborn/Enon)	16	9.13	33.87	0.50	6.03
45424 & 45409 (Huber Heights)	14	4.18	13.61	0.45	2.42
45415, 45407, 45405, 45416, 45322, 45426, 45408, 45417, 45428, 45406 & 45418 (West Dayton)	12	7.01	33.81	1.68	3.50
45373 & 45344 (New Carlisle/Troy)	6	9.66	22.00	1.96	5.15
Total	107	6.22	39.09	0.30	3.70

Table VII: Results of Radon Measurements in pCi/l (Basement)

Zip Codes (Region)	Number of Measurements	Average	High	Low	Median
45432, 45459 & 45305 (Miamisburg/Bellbrook)	12	7.43	24.60	0.74	3.31
45440 & 45429 (Kettering)	7	5.95	10.77	1.43	6.96
45430, 45420, 45419 & 45409 (Beavercreek/Oakwood)	6	7.91	23.65	1.30	5.49
45432 & 45431 (Beavercreek/Riverside)	10	8.58	51.01	0.58	3.92
45385 & 45301 (Xenia)	8	18.13	36.05	5.36	15.22
45324, 45435, 45323 & 45387 (Fairborn/Enon)	9	14.99	41.00	1.63	11.21
45424 & 45409 ((Huber Heights)	7	5.54	11.68	1.15	4.00
45415, 45407, 45405, 45416, 45322, 45426, 45408, 45417, 45428, 45406 & 45418 (West Dayton)	11	10.96	44.53	2.95	10.10
45373 & 45344 (New Carlilse/Troy)	6	17.21	29.00	3.12	20.03
Total	76	10.75	51.01	0.58	7.32

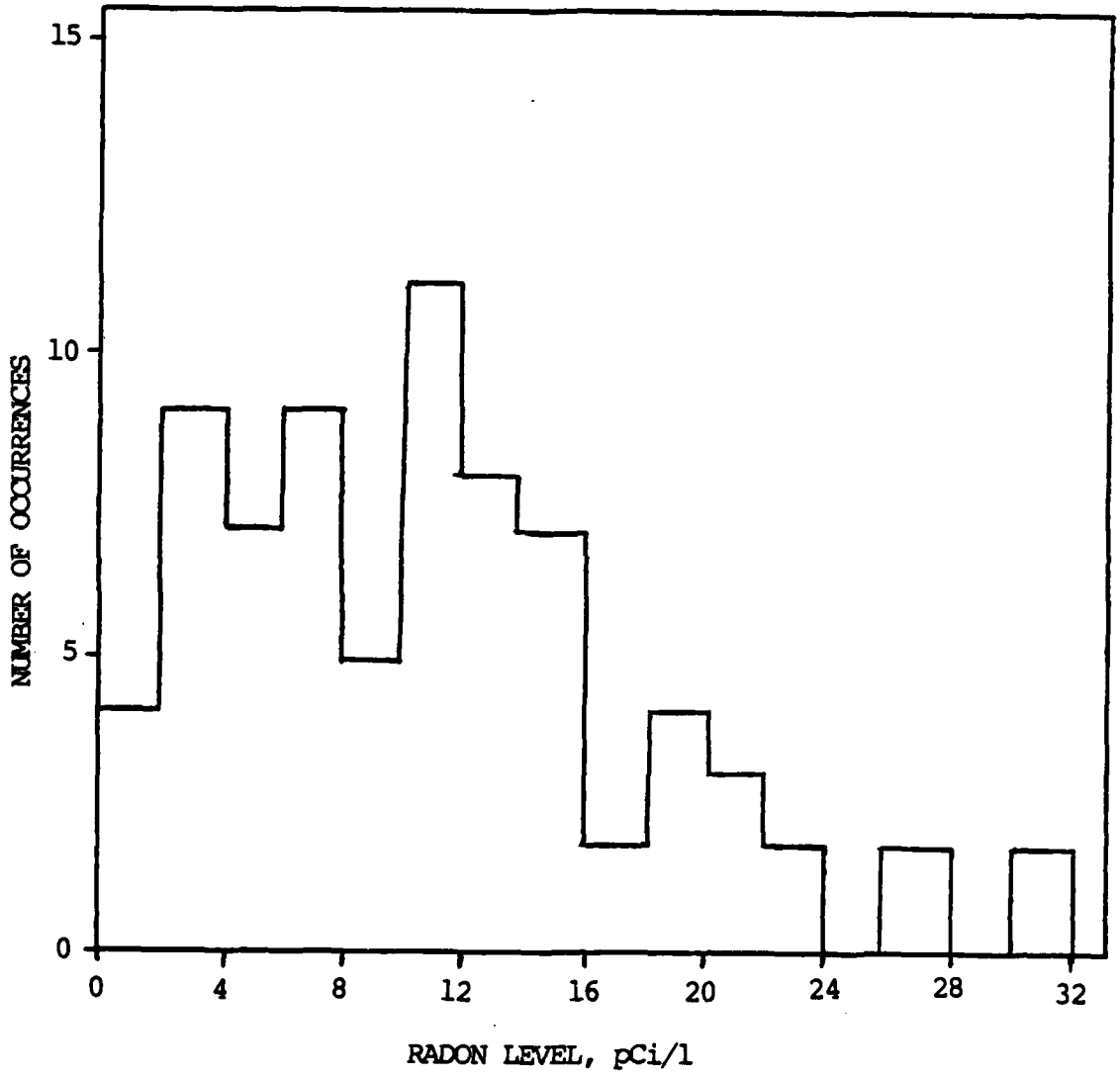

Figure 9. Frequency of Occurrence by Radon Level (First Floor)

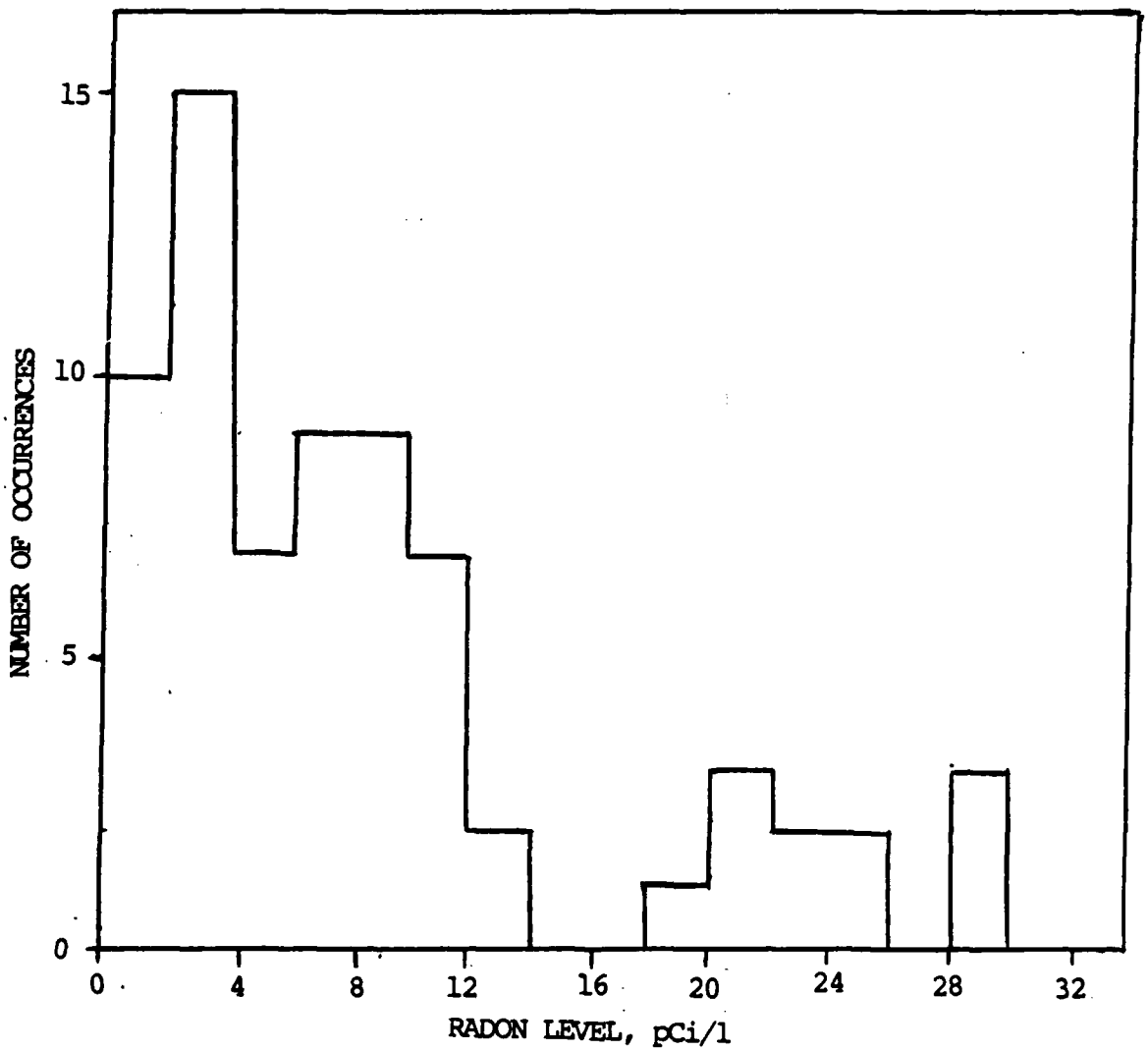

Figure 10. Frequency of Occurrence by Radon Level (Basement)

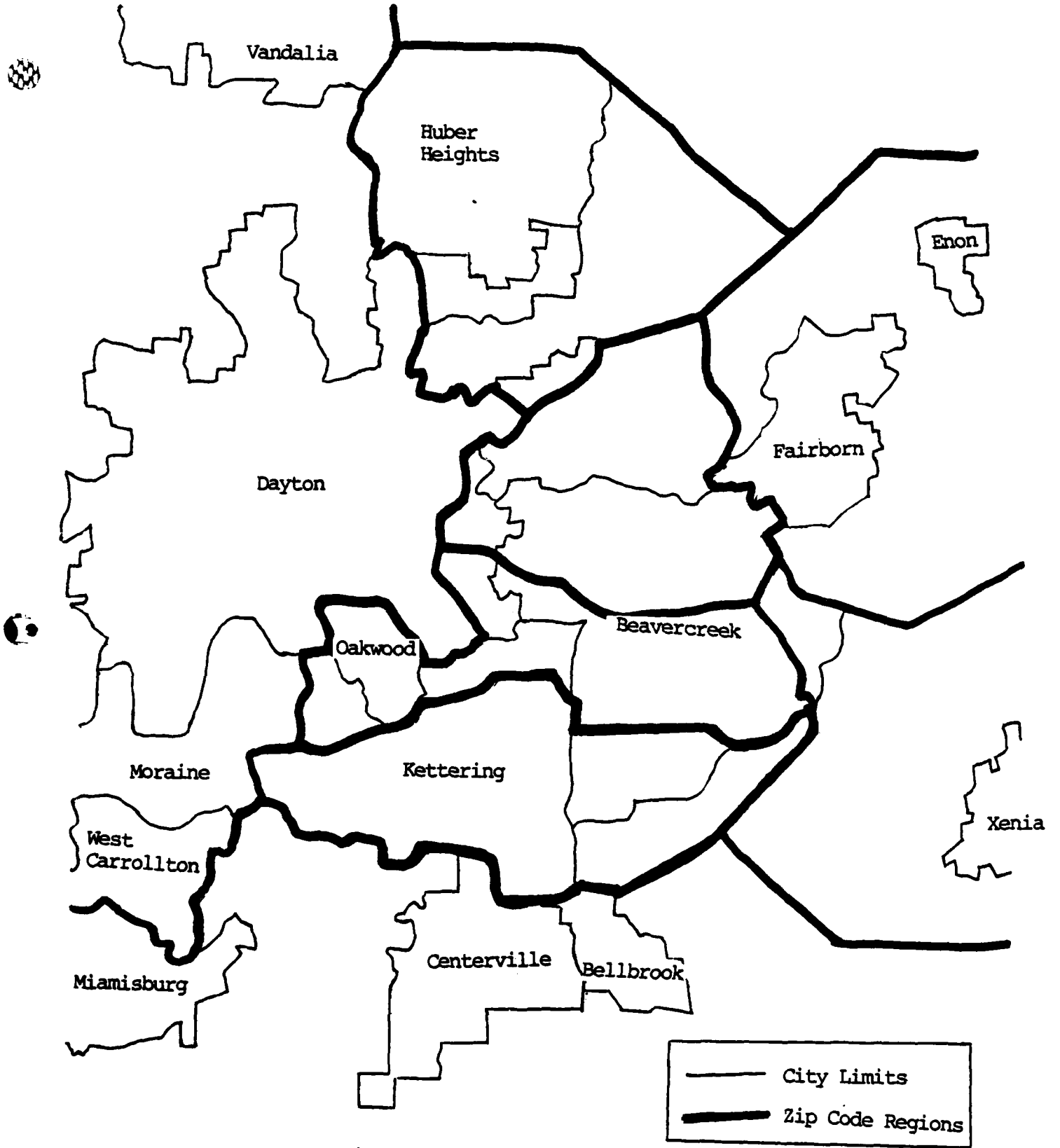

Figure 11. Zip Code Regions

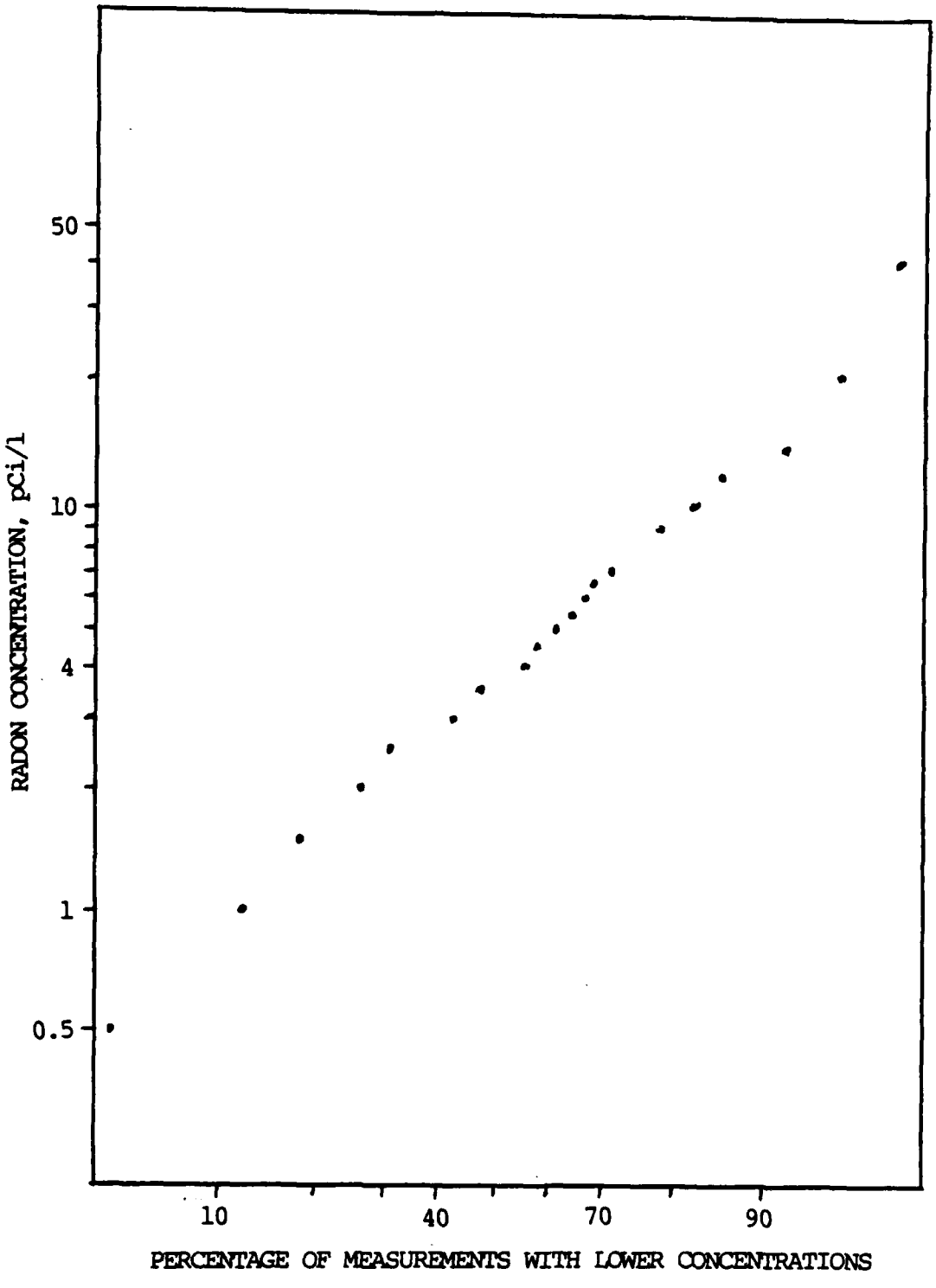

Figure 12. Distribution of First Floor Radon Measurements

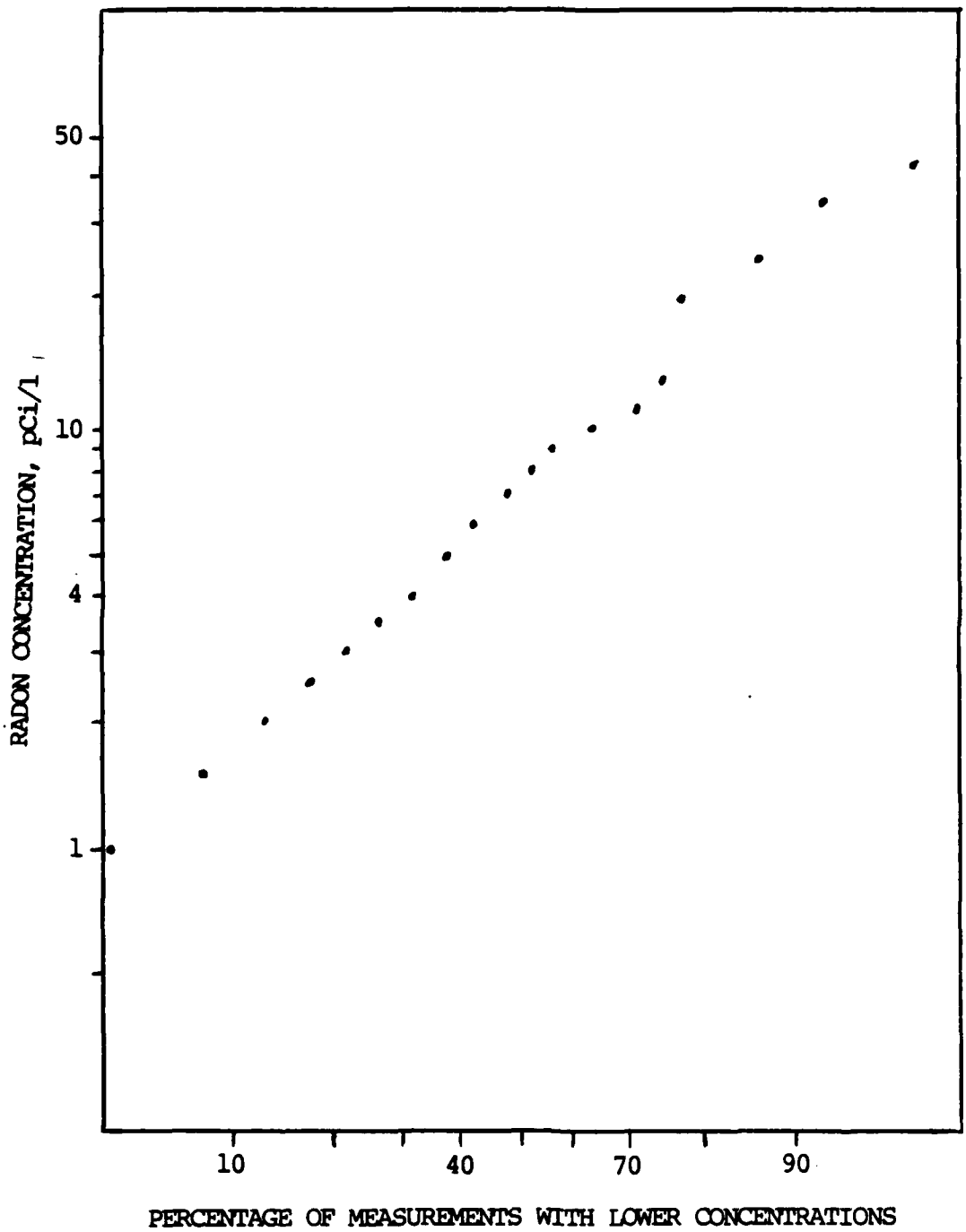

Figure 13. Distribution of Basement Radon Measurements

Radon Diffusion

Radon diffusion was studied using Glad Wrap, Silastic, and condom material as diffusion barriers. An initial study was done to demonstrate the reproducibility of results using two canisters with no radon barrier. The canisters were exposed to radon in the radon chamber after which the radon was allowed to diffuse from the canisters over a two-week period. A least squares fit to the data was made after it had been corrected for decay. The first canister gave a halflife for radon diffusion of 100.0 +/- 4.0 hours and 92.6 +/- 1.7 hours. The second canister gave a diffusion halflife of 94.3 +/- 0.9 hours and 104.1 +/- 3.4 hours. The quadratic fit program is listed in Appendix C. The results of the diffusion study are shown in Table VI. An infinite halflife for the Glad wrap and condom material are shown since the quadratic fit gave a positive slope to the data.

TABLE VI: Radon Diffusion Through Materials

Material	Halflife (hours)
Condom	Infinite
Glad Wrap	Infinite
Silastic (With Screen)	2000 +/- 500
Silastic (Without Screen)	198.5 +/- 26.3

IV. CONCLUSIONS AND RECOMMENDATIONS

Radon Chamber. The results from the radon source study demonstrate the advantage of evaporated radium, over radium in solution as a radon source. The evaporated source eliminates HCl fumes inside the chamber which create a corrosive environment for any instrumentation, while still producing the same concentration of radon as the source in solution. The evaporated source eliminates the high humidity within the chamber caused by the HCl solution. The variability of the radon within the chamber is still a problem with the evaporated source which could be due to a combination of leakage from the chamber and variability of the source. The halflife for radon in the chamber indicates considerable leakage from the chamber, most of which is from the glovebox. Better sealing of the glovebox might decrease the variability, but to create the constant radon level desired, an active feedback system is necessary. Moisture should also be added from a separate source to maintain the humidity at the desired level. Another factor which would decrease the radon variation is increasing the volume of the chamber and increasing the activity of the source.

Fill Material Lucas Cell. The ability of the Lucas cell to detect radon emanation from fill material was demonstrated. With the equilibrium time of over two weeks, any future fill material study must be long enough to allow for this equilibrium time. A second Lucas cell would make a comparison between fill material around homes with low radon levels and homes with high radon levels much easier. Further work on

improving the calibration factor is needed since the calibration factor used is based on one sample taken from the radon chamber. Taking several samples at different radon concentrations would allow a better calibration factor to be determined.

Radium Content. To determine the radium content of fill material more information is necessary. The efficiency of the NaI detector for fill material in the container geometry is needed. A first cut at the efficiency can be made by putting a known amount of radium in solution and making several 4-hour counts on the NaI detector. Due to the large gamma background as compared to the radon and progeny counts in the 4-hour counts, a method of determining the background accurately is required. A least squares or quadratic fit to the data on both sides of the counting energy regions would accomplish this. Several separate runs should be made to lower the statistical variation of the radon and progeny counts.

Radon in Homes. Additional radon measurements are needed in Dayton-area homes to get a more complete view of the pattern of elevated radon levels. The trend in the existing data indicates there are a greater percentage of elevated radon levels in homes to the north and east of Dayton including the Enon, Fairborn, New Carlisle, and Troy zip code areas. Although there are still low radon levels found in homes in these areas, there are a greater number of radon measurements above 6 pCi/l. To verify this trend more measurements are required. When

radon measurements are taken in the future, basement measurements should be taken when possible to allow fill material studies to be made. First floor measurements of radon are not always indicative of the radon levels in basements.

The charcoal canisters used for radon measurements could be improved by finding humidity corrections for the canisters. Although the canisters had been calibrated at three different humidities, these were not enough humidities to allow for good correction factors. The variations found during the calibration of the canisters did not vary by more than 8% between 25 and 80 percent humidities. Another possible method of correcting for humidity variations would be to find a material that is permeable to radon but not very permeable to moisture. If such a material is found, it could be used over the holes in the canisters. The last improvement to the canisters would be to use larger pieces of duct tape to cover the canister holes before and after radon measurements. The duct tape used leaves very little overlap around the hole.

The log-normal distribution found for the radon measurements agrees with the result found by Cohen (2:175-183). Cohen did an extensive study of radon measurements across the U.S. and found a log-normal distribution with a median of 1.05 pCi/l, a mean of 1.03 pCi/l and an average of 1.47 pCi/l. These values are much lower than the values found in this study of a median value of 3.7 pCi/l, a mean of 3.90 pCi/l and an average of 6.22 pCi/l. The radon concentrations in this study are higher than Cohen's study for two reasons. Most of these measurements were taken

in the Fall while Cohen's study used year-round measurements. Another reason is that Dayton-area homes have higher than national average radon levels.

Radon Diffusion. The diffusion of radon through the three materials did not produce a candidate which could be used as covers for canisters or as a source cover for a liquid radon source. It is difficult to calculate the diffusion coefficient since measurements were taken over a two-week period and the diffusion times are much longer. The problem with the method used was that the canisters were exposed in the radon chamber which was at 25-35 pCi/l. This meant that after only 2 weeks the radon and progeny counts approached the background level. If the radon level in the chamber could be increased to 60 pCi/l or higher, the length of time over which data could be collected would be increased. Another option which could be used in conjunction with increasing the radon exposure level is to increase the size of the canister holes used for diffusion calculations. By increasing the surface area which the radon can diffuse through, the radon will more readily diffuse before the radon and progeny decay.

APPENDIX A: DEFINITION OF WORKING LEVEL

In the field of health physics, working level (WL) is a unit of measure which is applied to radon decay products' concentrations in air. WL has a definite but sometimes misunderstood definition. The definition used today in the United States and Canada is: "One WL is any combination of the short-lived decay products of radon (RaA, RaB, RaC, and RaC') in one liter of air that will result in the ultimate emission by them of $1.3X10^5$ MeV of alpha ray energy."

The WL unit was introduced in 1957 after it was determined that the most significant natural source of radiation exposure to the lungs, and thus the highest risk of lung cancer, was from radon decay products. WL only applies to alpha radiation since the beta and gamma rays emitted by radon decay make a negligible contribution to the radiation dose the lung receives.

Precise measurement using the WL is very difficult since it requires knowledge of the concentrations of each of the radon decay products. If all the decay products were at equilibrium, they would be at the same concentration. This is seldom the case however, so the decay products must be measured or assumptions must be made about their concentrations. Determining the concentrations of the decay products is a difficult task requiring that a series of separate measurements be made. An alternative method is to use the working level ratio (WLR). The WLR is the fraction

given by the decay product alpha ray energy in air divided by the alpha ray energy which would be available if all the decay products were in equilibrium with radon. If the decay products are in equilibrium with radon the ratio would be 1.0. The assumption generally made is that the WLR is 0.5. This is based on extensive measurements which have been made in the field. By measuring the radon concentration and using the WLR of 0.5, a measurement using the WL unit can easily be calculated.

A sample calculation using the WL would be as follows. First the radon concentration would be measured. Assuming the decay products are in equilibrium with radon, the total alpha energy available is calculated. Then this value is multiplied by the WLR of 0.5 to give the decay product alpha energy. This value is then divided by $1.3X10^5$ to give the value in WLs.

There are several limitations on the WL unit. The first limitation is that no consideration is made of the altitude at which the measurements are taken. At higher altitudes the density of air is less than at lower altitudes. Since the WL unit definition uses one liter of air, the density of air would affect the WL value found. Another limitation is that no consideration is made of the fraction of the decay products which are retained in the lungs. This fraction of decay products varies among individuals. Although the WL unit has these limitations, it is still the best method for evaluating the effect of radon decay products on man.

APPENDIX B: DETAILED DESCRIPTION OF EQUIPMENT

Lucas Cell

The Lucas cell consists of a 5 inch section of opaque PVC pipe 20 inches long with a thin layer containing ZnS[Ag] on the inside wall of the cell. A clear polyethylene window sealed the bottom end of the air-tight cell. A valve in the top of the cell was used for evacuating and grab sampling with the cell. The detector used for measuring the Lucas cell is a light-tight metal tube with a photomultiplier tube in the bottom end. A drawing of the Lucas cell is shown in Figure B-1 with the detector set up is shown in Figure B-2.

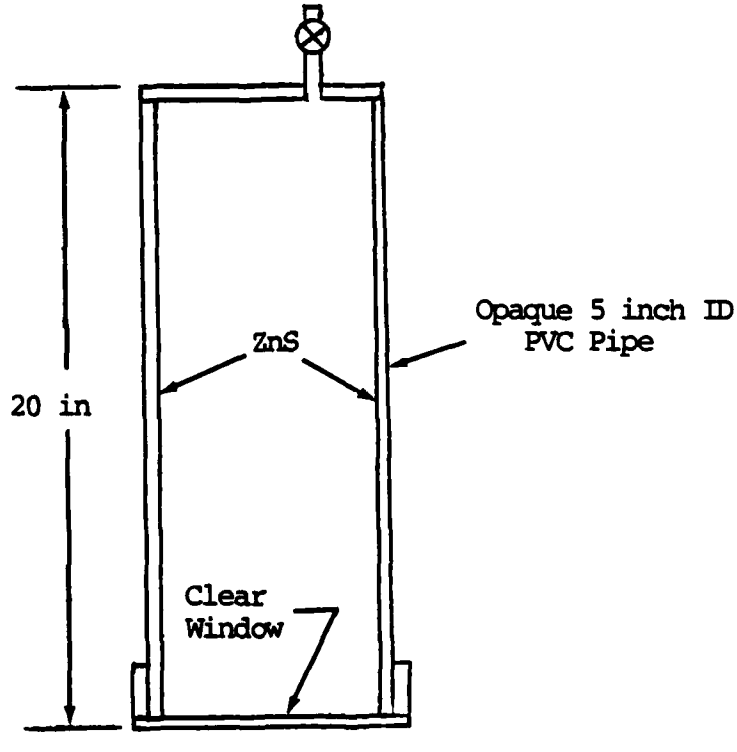

Figure 14. Lucas Cell

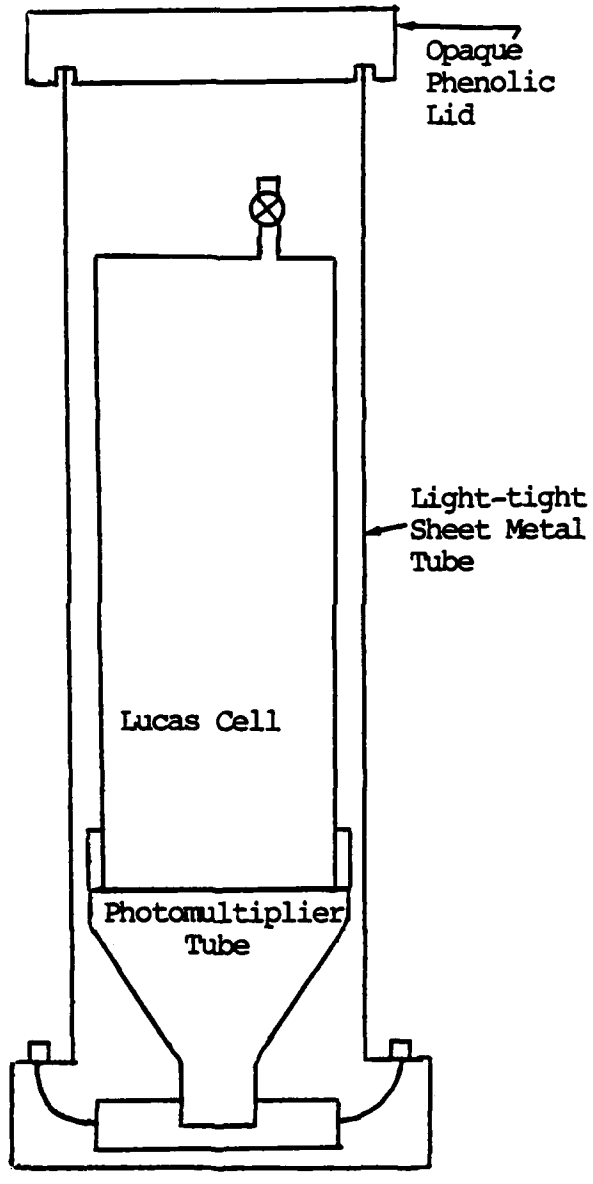

Figure 15. Lucas Cell Detector

Continuous Radon Monitor

The continuous radon monitor is a modified Lucas cell. 3/8 inch tubing through two holes in the lid of the cell is used for circulating air through the cell. One tube went to the bottom of the cell while the other tube went into the top of the cell. A drawing of the continuous monitor is shown below.

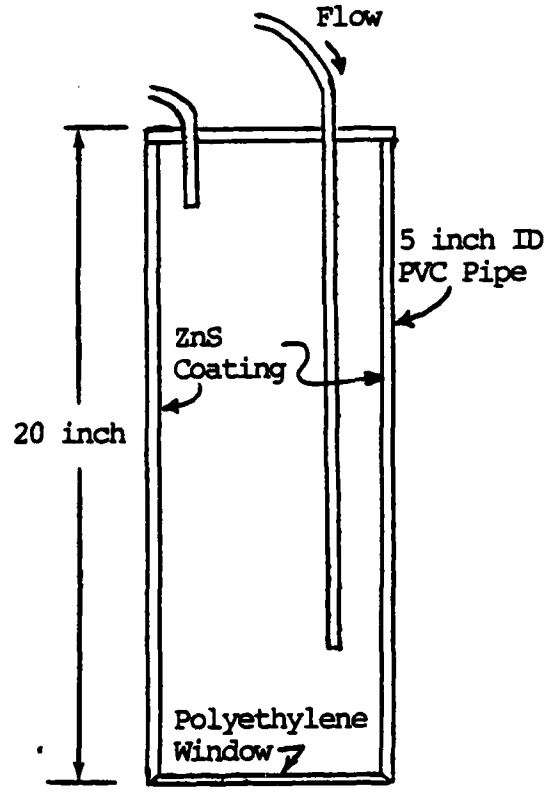

Figure 16. Continuous Monitor

Fill Material Lucas Cell

A modified Lucas cell is used for measuring the radon emanation from fill material. The cell consists of a section of 4 inch PVC pipe 19 inches long with a removable lid used to seal the top of the cell. A wire basket in the top of the cell was used to hold the fill material. The cell was air-tight when the lid was sealed and a valve in the lid was used for grab sampling. A drawing of the cell is shown below.

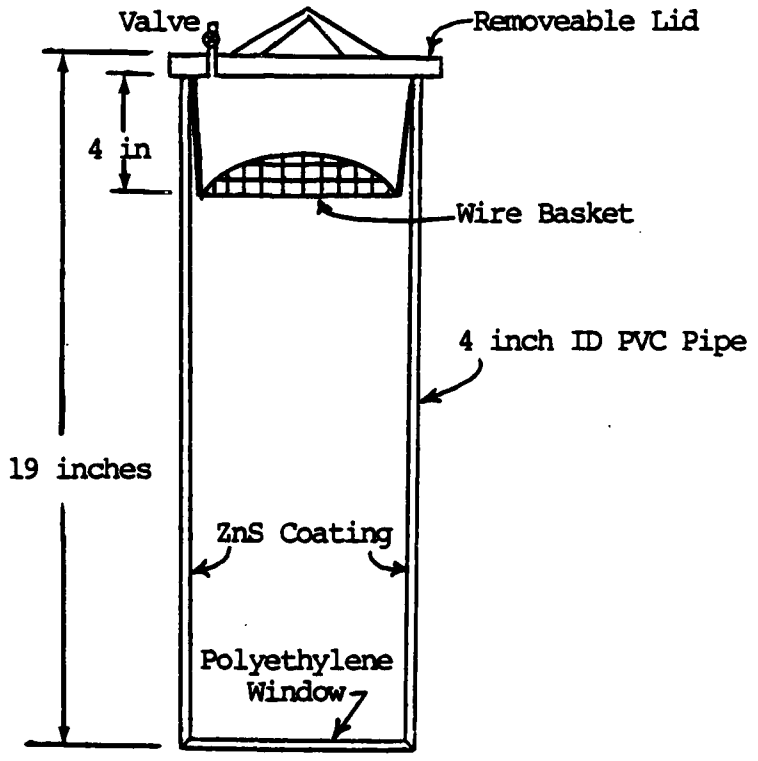

Figure 17. Fill Material Lucas Cell

Charcoal Canisters

The charcoal canisters are metal ointment cans 4 inches in diameter and 1 inch thick. A 3/4 inch diameter hole in the top of the can allows radon to diffuse into the canister. A layer of silk screen mesh across the hole serves as a turbulence barrier which ensures an initial diffusive flow into the canister. A piece of duct tape covered the hole between tests. The cans were partially filled with activated charcoal which was held in place by a wire screen. The charcoal was 1.5 cm in depth and contained approximately 150 grams of 200 mesh charcoal. Drawings showing the canisters are shown below.

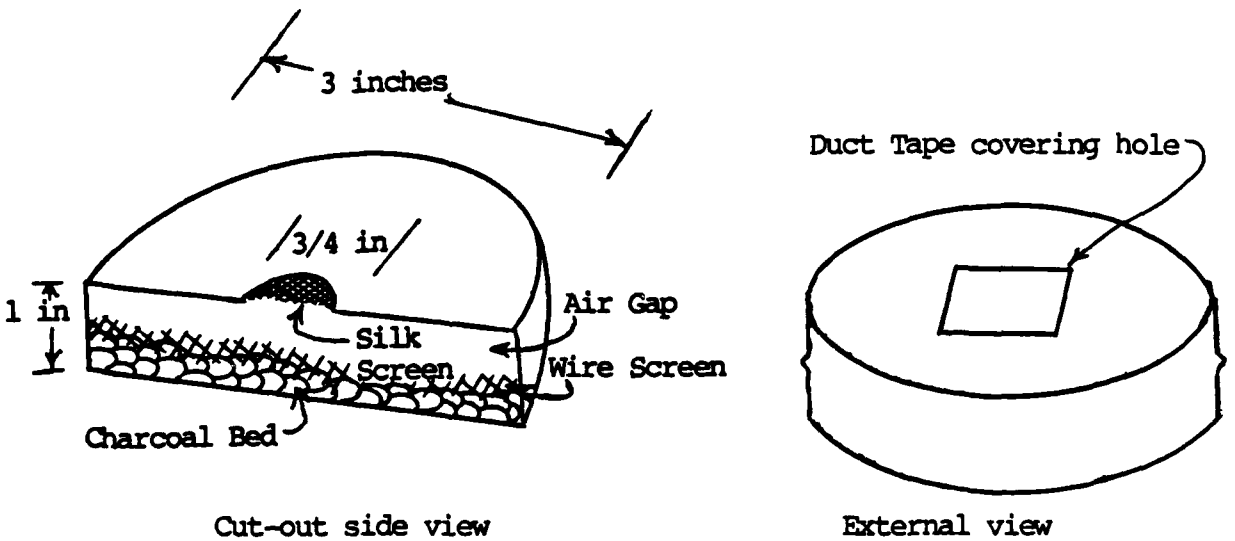

Figure 18. Charcoal Canister

APPENDIX C: COMPUTER PROGRAMS

Program "RADON"

```
10  '*************************************************************************
    RADON  Finds the Rn 222 concentration in pCi/l detected by a detector can
    from the number of Pb 214 gamma counts in the 220-390 KeV band and the
20  'number of Bi 214 counts in the 550-680 KeV band in a 30 minute count.  The
    counts should include background because this program subtracts background
    as part of its calculation.  Files LEADBG (containing 220-390 KeV back-
30  'ground) and BISBG (containing 550-680 background) must be on the same disk
    as this program.  Output of Rn 222 in pCi/l is to the screen and to the
    disk file RADON. Major Variables are:
40  'LEAD.............Number of counts between 220-390 KeV in a 30 minute count
    BIS..............Number of counts between 550-680 KeV in a 30 minute count
    LEADBG...........220-390 KeV background counts for a 30 minute count
50  'BISBG............550-680 KeV background counts for a 30 minute count
    LEADCOUNTS.......220-390 KeV counts from can less background
    BISCOUNTS........550-680 KeV counts from can less background
60  'TOTALCOUNTS.....Sum or LEADCOUNTS & BISCOUNTS
70  'T................Time (input in hours, converted to seconds by program)
                      between cans were removed and sealed and the time the
                      count was STARTED.  MUST BE AT LEAST FIVE HOURS!
80  'NO...............Number of Rn 222 atoms in 1 liter at a concentration of
                      1 pCi/l
    NLEAD............Number of Pb 214 atoms in 1 liter at time T seconds from
90  '                 an initial Rn 222 concentration of 1 pCi/l
    NBIS.............Number of Bi 214 atoms in 1 liter at time T seconds from
                      an initial Rn 222 concentration of 1 pCi/l
100 'ALEAD............Activity (in Bq) per liter of NLEAD Pb 214 atoms
    ABIS.............Activity (in Bq) per liter of ABIS Bi 214 atoms
    LEADDECAYS.......Pb 214 Decays from 1 pCi/l of Rn 222 at time T
110 'BISDECAYS........Bi 214 Decays from 1 pCi/l of Rn 222 at time T
    CAN..............Detector can's lable number
    SIGLEAD..........Statistical uncertainty in 220-390 KeV count
120 'SIGBIS...........Statistical uncertainty in 550-680 KeV count
    SIGLBG...........Statistical uncertainty in 220-390 KeV background count
    SIGBBG...........Statistical uncertainty in 550-680 KeV background count
130 'SIGLC............Uncertainty in LEADCOUNTS
    SIGBC............Uncertainty in BISCOUNTS
    SIGTC............Uncertainty in TOTALCOUNTS
140 'SIGDECAY.........Uncertainty in sum of LEADDECAYS & BISDECAYS
    TOTALDECAYS......Sum of LEADDECAYS & BISDECAYS
    CALFACTOR........Calibration factor determined from can's exposure in
150 '                 Mound's Radon chamber that account's for geomerty factors,
                      the can's sensitivity, the Na(I) Scintillator/ND-100
160 '                 Gamma-ray detection efficiency, and branching fractions
    RADONCON.........Radon concentration in pCi/l detected by the can
    SIGRC............Uncertainty in RADONCON
170 'SIGCF............Uncertainty in CALFACTOR
180 '*************************************************************************
190 OPEN "radon" FOR OUTPUT AS #2.
200 PRINT #2, "Can No.     Hours Since Sealed     Radon Conc. (pCi/l)     Uncert
```

```
ainty (pCi/l)"
210 GOSUB 1000 :'***Establish Background Level***
220 INPUT "Type D to input data from disk file CANS or K to input data from the
keyboard. ",OPT$
230 IF OPT$ = "d" OR OPT$ = "D" THEN PRINT "Can No.     Hours Since Sealed     R
adon Conc. (pCi/l)     Uncertainty (pCi/l)"
240 IF OPT$ = "d" OR OPT$ = "D" THEN GOSUB 2000
                                ELSE GOSUB 3000
250 LEADCOUNTS = LEAD - LEADBG :'***Subtract Background***
260 SIGLC = SQR( SIGLEAD^2 + SIGLBG^2 )
270 BISCOUNTS = BIS - BISBG
280 SIGBC = SQR( SIGBIS^2 + SIGBBG^2 )
290 TOTALCOUNTS = LEADCOUNTS + BISCOUNTS
300 SIGTC = SQR( SIGLC^2 + SIGBC^2 )
310 T = T * 3600 : '**Convert hours to seconds**
320 A0 = 1 :'**Base calculation on concentrations of 1 pCi/liter**
330 NRN = (A0*.037/.0000021)*EXP( -T * 2.16E-06 ) :'***Number of Rn 222 atoms
                                                    per liter at time t seconds***
340 NLEAD = NRN :'**Assume transient equilibrium at times greater than 5 hours**
350 ALEAD = .000431*NLEAD :'**Pb 214 activity in Bq**
360 NBIS = NRN :'**Assume transient equilibrium at times greater than 5 hours**
370 ABIS = ( .000584 )*NBIS :'**Bi 214 activity in Bq**
380 LEADDECAYS = ALEAD * 27 * 4000 * 1800 * (1/1000) :'*** Pb 214 activity in Bq
    * 27 gm charcoal * 4000 cm^2/gm (for charcoal) * 1800 seconds count time
    * ( 1 liter/1000 cm^2) ***
390 BISDECAYS = ABIS * 27 * 4000 * 1800 * (1/1000) :'*** Bi 214 activity in Bq
    * 27 gm charcoal * 4000 cm^2/gm (for charcoal) * 1800 second count time
    * ( 1 liter/1000 cm^2 ) ***
400 TOTALDECAYS = LEADDECAYS + BISDECAYS
410 SIGDECAY = SQR( (.0006296*LEADDECAYS)^2 + (.0006296*BISDECAYS)^2 ) :'
    *** See Lab Notebook p. 85 for calculation of SIGDECAY ***
420 CALFACTOR = 7468
430 SIGCF = 24.5  :'*** See Lab Notebook p. 87 ***
440 RADONCON = ( TOTALCOUNTS/TOTALDECAYS ) * CALFACTOR
450 SIGRC = RADONCON * SQR( (SIGTC/TOTALCOUNTS)^2 + (SIGDECAY/TOTALDECAYS)^2
                          + (SIGCF/CALFACTOR)^2 )
460 PRINT USING "  ###              ###.##              ####.##
####.##     "; CAN; (T/3600)-.25; RADONCON; SIGRC
470 PRINT #2, USING "  ###              ###.##              ####.##
    ####.##     "; CAN; (T/3600)-.25; RADONCON; SIGRC
480 GOTO 240
1000 '*************************************************************************
                  Change Background Count Subroutine
     *************************************************************************
1010 OPEN "leadbg" FOR INPUT AS #1
1020 INPUT #1, LEADBG
1030 CLOSE #1
1040 PRINT USING "The 220-390 KeV background count for a 30 minute count time to
 be used in this  calculation is ####";LEADBG
1050 INPUT "Do you want to change it? (y or n) ", ANS$
1060 IF ANS$ = "n" OR ANS$ = "N" THEN 1110
1070 INPUT "What 220-390 KeV background count for a 30 minute count time do you
want to use? ",LEADBG
1080 OPEN "leadbg" FOR OUTPUT AS #1
1090 PRINT #1, LEADBG
1100 CLOSE #1
1110 OPEN "bisbg" FOR INPUT AS #1
1120 INPUT #1, BISBG
1130 CLOSE #1
```

```
1140 PRINT USING "The 550-680 KeV background count for a 30 minute count time to
 be used in this calculation is ####";BISBG
1150 INPUT "Do you want to change it? (y or n) ",ANS$
1160 IF ANS$ = "N" OR ANS$ = "n" THEN 1210
1170 INPUT "What 550-680 KeV background count for a 30 minute count time do you
want to use? ",BISBG
1180 OPEN "bisbg" FOR OUTPUT AS #1
1190 PRINT #1, BISBG
1200 CLOSE #1
1210 SIGLBG = SQR(LEADBG)
1220 SIGBBG = SQR(BISBG)
1230 RETURN
2000 '*****************************************************************************
                    Input from Disk File Subroutine
     *****************************************************************************
2010 ON ERROR GOTO 2100
2020 OPEN "cans" FOR INPUT AS #3
2030 IF EOF(3) THEN 2080
2040 INPUT #3, CAN, T, LEAD, BIS
2045 T = T + .25
2050 SIGLEAD = SQR(LEAD)
2060 SIGBIS =  SQR(BIS)
2070 RETURN
2080 CLOSE #3
2090 END
2100 IF ERR = 55 THEN RESUME NEXT ELSE ON ERROR GOTO 0
3000 '*****************************************************************************
                    Input from Keyboard Subroutine
     *****************************************************************************
3010 INPUT "What is the can number? (Enter 0 to quit) ",CAN
3020 IF CAN = 0 THEN 3100
3030 INPUT "How long, in hours, was it between the time the can was sealed and t
he time the count was started? ",T
3035 T = T + .25
3040 INPUT "How many 220-390 KeV counts in 30 minutes ",LEAD
3050 INPUT "How many 550-680 KeV counts in 30 minutes ",BIS
3060 SIGLEAD = SQR(LEAD)
3070 SIGBIS = SQR(BIS)
3080 PRINT "Can No.     Hours Since Sealed     Radon Conc. (pCi/l)     Uncertain
ty (pCi/l)"
3090 RETURN
3100 END
```

Program "QUADFIT"

```
30 DIM X(1000) , Y(1000)
40 OPEN "points" FOR INPUT AS #1
50 OPEN "quad" FOR OUTPUT AS #2
60 N = 1
70 IF EOF(1) THEN 180
80 INPUT #1, X(N) , Y(N)
90 XSUM = XSUM + X(N)
100 YSUM = YSUM + Y(N)
110 XYSUM = XYSUM + X(N)*Y(N)
120 X2SUM = X2SUM + X(N)^2
130 X3SUM = X3SUM + X(N)^3
140 X4SUM = X4SUM + X(N)^4
150 X2YSUM = X2YSUM + ( X(N)^2 )*Y(N)
160 N = N + 1
170 GOTO 70
180 N = N-1
190 DELTA = N*( X2SUM*X4SUM - X3SUM*X3SUM ) - XSUM*( XSUM*X4SUM - X2SUM*X3SUM )
          + X2SUM*( XSUM*X3SUM - X2SUM*X2SUM )
200 A = YSUM*( X2SUM*X4SUM - X3SUM*X3SUM ) - XSUM*( XYSUM*X4SUM - X2YSUM*X3SUM )
      + X2SUM*( XYSUM*X3SUM - X2YSUM*X2SUM )
210 A = A/DELTA
220 B = N*( XYSUM*X4SUM - X2YSUM*X3SUM ) - YSUM*( XSUM*X4SUM - X2SUM*X3SUM )
      + X2SUM*( XSUM*X2YSUM - X2SUM*XYSUM )
230 B = B/DELTA
240 C = N*( X2SUM*X2YSUM - X3SUM*XYSUM ) - XSUM*( XSUM*X2YSUM - X2SUM*XYSUM )
        + YSUM*( XSUM*X3SUM - X2SUM*X2SUM )
250 C = C/DELTA
260 FOR I = 1 TO N
270     FITSUM = FITSUM + ( Y(I) - A - B*X(I) - C*X(I)^2 )^2
280 NEXT I
290 PRINT #2, USING "The quadradic fit is: ##.####^^^^  +  ##.####^^^^*X  +  ##.
####^^^^*X^2";A;B;C
300 PRINT #2, ""
310 IF N<=3 THEN PRINT #2, "Too few datapoints for a correct variance":GOTO 350
320 VARIANCE = ( 1/(N - 2 -1) )*FITSUM
330 SD = SQR(VARIANCE)
340 PRINT #2, USING "The sample standard deviation for this fit is:  ##.####^^^^
";SD
350 PRINT #2, ""
360 PRINT #2, "    X             Y            Fit Y(x)  "
370 FOR I = 1 TO N
380 PRINT #2, USING " #####.##      #####.##       #####.##"; X(I); Y(I); (A +
B*X(I) + C*X(I)^2)
390 NEXT I
400 CLOSE :SYSTEM
410 END
```

APPENDIX D: DATA FROM RADON MEASUREMENTS IN HOMES IN THE GREATER DAYTON AREA

TABLE IX: Radon data for Zip Codes 45432,45459, and 45305 (Miamisburg, Centerville, and Bellbrook)

First Floor(or main level) Radon Measurement (pCi/l)	Basement (or lower level) Radon Measurement (pCi/l)
6.71 *	2.71 *
3.88 *	7.92 *
5.14	9.95 *
1.37	2.29
0.88	1.76
8.40 *	9.15 *
0.62 *	0.74 *
1.80 *	2.37 *
3.88	24.60
8.88	2.29
1.37	21.52
8.53	3.91
3.35	
1.85	
15.99	

* Data taken by prior students

TABLE X: ZIP CODES 45440, 45429 (Kettering)

First Floor (pCi/l)	Basement (pCi/l)
4.66	6.96
7.10	8.30 *
0.30 *	8.12
2.89 *	10.77
2.44	1.43 *
13.90	3.29
0.89	2.75
3.09	
2.54	
1.02 *	
3.75	
9.04	

* Data taken by prior students

TABLE XI: ZIP CODES 45430, 45420, 45419, 45409 (Southern Beavercreek to Oakwood)

First Floor (pCi/l)	Basement (pCi/l)
9.89 *	9.91 *
9.30	7.14 *
1.77	3.83 *
6.75 *	1.64 *
2.87 *	23.65
0.71 *	1.30
5.67	
1.13	

*Data taken by prior students

TABLE XII: ZIP CODES 45432, 45431 (Northern Beavercreek to Riverside)

First Floor (pCi/l)	Basement (pCi/l)
3.34 *	3.48 *
39.09 *	51.01 *
3.70 *	9.16 *
0.89 *	1.03 *
1.80 *	4.41 *
2.86	5.25
3.21	3.74
3.26	0.58
4.06	3.04
1.00	4.09
3.58	
0.34	
4.61	
12.88	
2.00	

* Data taken by prior students

TABLE XIII: ZIP CODES 45385, 45301 (XENIA)

First Floor (pCi/l)	Basement (pCi/l)
18.60 *	21.40 *
8.47 *	36.05 *
0.78 *	9.04 *
3.80	22.62
2.26	8.08
9.40	7.51
4.70	5.36
10.27	34.96
12.06	

* Data taken by prior students

TABLE XIV: Radon Data for ZIP CODES 45324, 45433, 45323, 45377 (Fairborn, Enon, and Yellow Springs)

First Floor (pCi/l)	Basement (pCi/l)
22.26 *	29.70 *
0.69 *	1.63 *
5.00 *	7.91 *
4.82 *	10.22 *
10.00 *	41.0 *
20.44 *	28.70 *
1.98	12.19
2.78	6.90
33.87	37.63
7.06	
12.03	
3.11	
8.68	
3.25	
9.68	
0.50	

* Data taken by prior students

TABLE XV: Radon for ZIP CODES 45424, 45409 (Huber Heights, Mad River)

First Floor (pCi/l)	Basement (pCi/l)
1.90 *	2.38 *
0.48 *	4.00 *
8.14 *	11.15 *
1.22	11.68
2.41	6.81
12.16	1.65
8.26	1.15
2.43	
0.93	
13.61	
2.64	
1.00	
2.95	
0.45	

* Data taken by prior students

TABLE XVI: Radon Data for ZIP CODES 45415, 45407, 45405, 45416, 45322, 45426, 45408, 45417, 45428, 45427, 45406, 45418 (Trotwood, Englewood, Harrison Township)

First Floor (pCi/l)	Basement (pCi/l)
2.77 *	2.95 *
1.92 *	10.18 *
3.45 *	4.49 *
6.18 *	13.70 *
8.66 *	10.62 *
2.50 *	6.24 *
2.64 *	3.84 *
5.48	10.10
33.81	4.34
1.68	44.53
11.39	9.52
3.74	

* Data from prior students

TABLE XVII: Radon Data for Zip CODES 45373, 45344 (New Carlisle and Troy)

First Floor (pCi/l)	Basement (pCi/l)
5.91 *	21.28 *
2.57 *	3.12 *
22.00 *	29.00 *
21.10 *	25.80 *
1.96	5.30
4.40	18.73

* Data from prior students

APPENDIX E: RADON CAN INSTRUCTION SHEET

RADON CAN INSTRUCTIONS

1. Select the location to be monitored. The highest concentration of radon gas is usually found in the basement near the floor drain. Place a can in this area. If you don't have a basement, place the can in any first floor room. If you have other cans, place them in any other room. Do not place two cans in the same room.

2. To start the test remove the duct tape from the top of the can and stick it on the side of the can. This exposes a hole in the top of the can that allows the radon to diffuse into the can. Record the time and date the can was opened on the form below. Leave the can undisturbed for three days.

3. After three days, end the test by placing the duct tape back over the hole in the top of the can. Assure the tape covers the hole completely. Record the time and date the can was sealed. Return the can as soon as possible within three days of the test completion date.

Fill in the information below:

NAME _____ ADDRESS _____
(incl ZIP)_____

Phone _____

CAN# _____ LOCATION OF CAN _____
(Floor of House/Room)

DATE AND HOUR OPENED _____

DATE AND HOUR SEALED _____

Second can:

CAN# _____ LOCATION OF CAN _____

DATE AND HOUR OPENED _____

DATE AND HOUR SEALED _____

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VITA

Captain Joseph P. Bouchard was born on 22 February 1958 in Centralia, Washington. He graduated from high school in Centralia in 1976 and enlisted in the Air Force in Columbus, Ohio in 1978. He attended Texas A&M University under the Airman Education and Commissioning Program and received the degree of Bachelor of Science in Nuclear Engineering in May 1983. Upon graduation he attended Officer Training School where he was commissioned in August 1983. His first assignment as an officer was as a Hardness and Survivability Project Officer at the Ballistic Missile Office where he remained until entering the School of Engineering, Air Force Institute of Technology, in August 1986.

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Thesis Chairman: Dr. George John,
Professor of Nuclear Engineering

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block 19 (continued)

Techniques were developed which will allow indoor radon measurements taken in the greater Dayton area with charcoal canisters to be related to local geology or fill material. A Lucas cell was built and calibrated for measuring radon emanation from fill material and a procedure was developed to find the radium content of fill material. Studies to attempt to determine the best radon source for a radon chamber were also made. Radon diffusion properties of three polyethylene-type materials were studied for possible use as moisture barriers in the charcoal canisters or as radon source covers.

The radon measurements taken showed a higher percentage of elevated radon measurements above 6.0 pCi/l in homes to the north and east of Dayton. This was based on 107 first floor measurements and 76 basement measurements.

Radon chamber studies were conducted on several radon sources including radium in HCl solution and evaporated sources. A clear advantage is demonstrated for the evaporated radon source. The ability of the glovebox to maintain a build-up of radon was also shown.

Radon emanation from fill material was measured using a Lucas cell modified to hold fill material in the cell. The ability of the Lucas cell to determine radon emanation is clearly demonstrated with an equilibrium time of just over two weeks.

Radon diffusion properties of condom material, Glad wrap, and Silastic material show that Glad wrap and condom material are nearly nonpermeable to radon, while Silastic has a 200-hour halflife for radon diffusion from inside the canisters. This indicates that Glad Wrap and condom material would not be useful as moisture barriers or source covers.

END

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